PUMP IRRIGATION PROBLEMS

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Among the many pump irrigation problems are those relating to total amount of water applied, the time necessary to pump a given amount of water, the horsepower requirements and motor size for given lift and rate of discharge, efficiency, the cost of power, and the total cost of pumping.

The following definitions, calculations, and tabulations should be helpful in working with pump irrigation problems.

DEFINITIONS

1. **Area**
   Acre - 43,560 square feet.

2. **Quantity of Water**
   Acre-foot - Amount of water to cover 1 acre 1 foot deep.
   One acre-foot - 43,560 cubic feet = 325,851 gallons.
   Acre-inch - Amount of water to cover 1 acre 1 inch deep
   $= \frac{325,851}{12} = 27,152$ gallons.
   Cubic Foot - 1,728 cu. in. = 7.481 gallons - approximately.
   7.5 gallons - Weight = 62.4 pounds.
   Gallon (U.S.) - 231 cubic inches - Weight = 8.3356 pounds.

3. **Rates of Flow**
   A. Cubic foot per second - cu. ft. per sec. - (Sometimes called "Second-foot") - a rate of flow such that a measure of 1 cu. ft. capacity would be filled each second. It is equal to 448.8 gallons per minute - approximately 450 g.p.m.

   B. Miner's Inch - a rate of flow through an orifice of 1 square inch area under heads which vary locally. In Montana a miner's inch is a rate of flow equal to 1/40 of 1 cubic foot per second. This rate is equal, approximately, to $11\frac{1}{4}$ gallons per minute, and is the rate of flow through an orifice of 1 square inch area under a head of 6 inches above the center of the orifice.

   C. Gallons per minute - g.p.m. - a rate of flow such that 1-gallon measure would be filled each minute. This rate of flow is equal, approximately, to 1/450 of a cubic foot per second.

4. **Rate of Work Units**

   When a given body is moved, work is done in accomplishing that movement. If a given quantity of water is raised a given height, a certain number of foot pounds of work will have been done. If a time factor in which to accomplish certain work is applied, the result is the necessary power.

   A. Power - is the time rate of doing work.

   B. Horsepower - hp. - 33,000 foot pounds of work per minute, or 550 foot pouhds of work per second = 746 watts or .746 kilowatt - approximately .750 kw.

   C. Kilowatt - kw. - 1,000 watts, the electrical unit of power.
   1 kw. $= \frac{1000}{746} = 1.34$ hp. - approximately 1-1/3 hp.

5. Total Work Units - rate of work x time.

   A. Horsepower-hour - 1 hp. for 1 hour = hp.-hr.

   B. Kilowatt-hour - 1 kw. for 1 hour = kw.-hr.

6. Lift or Head

   If a pump is discharging into the free atmosphere the lift is the difference in elevation between the water surface in the well when pumping and the water surface at the point of delivery, measured in feet.

   If a pump is discharging into a pipe line, the total head is the lift plus the pressure in the pipe line at the point of delivery from the pump, measured in feet of water.

   A. Foot of Water - is the hydrostatic pressure exerted by a column of water 1 foot high = 0.434 pound per square inch.

   B. Pound per square inch - 1 pound per square inch is equivalent to the pressure exerted by a column of water 2.31 feet high.

7. Water Horsepower (theoretical) - the work accomplished by a pump in lifting a certain quantity of water a certain height.

$$\text{Water horsepower} = \frac{\text{G.P.M. x Head (in feet)}}{3960}$$

$$\text{Water horsepower} = \frac{\text{Cu. Ft. Per Sec. x Head (in feet)}}{8.8}$$

The factor, $\frac{1}{3960}$, is equal to the weight of one gallon of water, 8.33 pounds, divided by 33,000, the conversion factor from foot-pounds per minute to horsepower.

8. Power Input to Motor - the rate of electrical power consumption of a motor is measured by timing the revolutions of the disk of the watt-hour meter located at the pump.

$$\text{kw.} = \frac{R \times K \times 3.6}{t}$$

where,

R = number of revolutions of disk in t seconds.
K = disk constant = watt-hours per revolution of the disk. (Usually found on name plate of meter).
3.6 = factor which is equal to 3600, the number of seconds in an hour, divided by 1000, the number of watts in a kilowatt.
t = time in seconds.

Large units require current and/or potential transformers; so that the watt-hour meter reading must be multiplied by the ratio of these transformers to obtain the correct measurement of power consumption of the motor.

Horsepower input to motor = kilowatt input x 1.34.

9. Efficiency - the ratio of the work accomplished to the amount of work expended $= \frac{\text{output}}{\text{input}}$.

$$\text{Over-all efficiency} = \frac{\text{water horsepower}}{\text{Horsepower input to motor}}$$

Over-all efficiency = motor efficiency x pump efficiency.

$$\text{Motor efficiency} = \frac{\text{brake horsepower of motor}}{\text{Horsepower input to motor}}$$

$$\text{Pump efficiency} = \frac{\text{water horsepower}}{\text{brake horsepower of motor}}$$

To express efficiency as a per cent, multiply by 100.

PROBLEMS

I. What depth of water will be applied to a given area in a given time with a given rate of discharge?

The fundamental unit of water measurement is the cubic foot per second. All other units of measurement can be expressed in terms of this unit.

1 cubic foot per second for 1 day = 60 x 60 x 24 = 86,400 cu. ft.
1 acre-foot = 43,560 cu. ft.
$\frac{86,400}{43,560} = 1.9834$, or approximately 2.0.
1 cubic foot per second for 1 day (24 hours) = 2.0 acre-feet = 24 acre-inches.
1 cubic foot per second = 1 acre-inch per hour.

The above relations are expressed as follows:

$$\frac{\text{cu. ft. per second x hours}}{\text{acres}} = \text{inches depth or acre-inches per acre.}$$

The above formula is written for other units of measurement as follows:

1. Miner's inches:

$$\frac{\text{Number miner's inches x hours}}{\text{40 x acres}} = \text{inches depth or acre-inches per acre.}$$

2. Gallons per minute:

$$\frac{\text{G.P.M. x hours}}{\text{450 x acres}} = \text{inches depth or acre-inches per acre.}$$

II. Computations of Horsepower. Useful in determining the size of motor required for a given set of pumping conditions.

The Rated Horsepower of a motor is the amount of power that the motor will develop when operating at full load.

The Brake Horsepower is the actual power that is being delivered to the shaft of the motor under any particular load.

The horsepower output of a motor = horsepower input x efficiency of motor.

The size of motor required depends upon the discharge of the pump, the total head under which the pump is operating, and the efficiency of the pump.

$$\text{hp. required} = \frac{\text{G.P.M. x head (in feet)}}{\text{3960 x pump efficiency}} \text{ or } \frac{\text{cu. ft. per sec. x head (in feet)}}{\text{8.8 x pump efficiency}}$$

Example: What size of motor is required to pump 700 gallons per minute against a head of 95 feet with a pump efficiency of 67.5 per cent?

$$\text{hp.} = \frac{700 \times 95}{3960 \times .675} = 25.0$$

III. Kilowatt-hours to pump 1 acre-foot.

The kilowatt-hours required to pump 1 acre-foot of water will vary as the total head and the over-all efficiency of the pumping plant. A convenient formula for determining the kilowatt-hours required to pump 1 acre-foot of water is as follows:

$$\text{kw.-hr.} = 1.024 \frac{h}{e}$$

where, h = total head
e = over-all efficiency, expressed decimally

Example: How many kilowatt-hours are required to pump 1 acre-foot of water with 95 feet of total head, pump efficiency of 67.5%, and motor efficiency of 89%?

Over-all efficiency = pump efficiency x motor efficiency
= 0.675 x 0.89
= 0.60, or 60%

$$\text{kw.-hr.} = 1.024 \frac{h}{e}$$
$$= 1.024 \frac{95}{.60}$$
$$= 162 \text{ kw.-hr.}$$

IV. Total Kilowatt-hours used per season.

In estimating the costs of operating a pumping plant, it is sometimes desirable to determine the total kilowatt-hours of power that will be used during an irrigating season. By applying the local power rates the power costs can be computed.

In determining the total kilowatts that will be used, it is necessary to find the total acre-feet of water that will be pumped and the kilowatt-hours required to pump one acre-foot of water. The product of these two factors is the total kilowatt-hours that will be used.

Example:

Area irrigated = 100 acres.
Water used per acre = 3 acre-feet.

Total acre-feet pumped = 300.
Kilowatt-hours to pump 1 acre-foot = 162
Total kw-hrs. used per season = 300 x 162 = 48,600 kw.-hrs.

V. Computation of cost of power.

Cost of power will be based on individual Cooperatives rates.

All power rates are very much alike. Usually they are divided into two parts:

a. A demand or readiness to serve charge, which is based on installed horsepower, is payable annually, and does not entitled pump owner to any electric energy.

b. Energy charge, which is billed at a variable rate, depending on the total number of kilowatt-hours used.

TYPICAL POWER PUMPING RATES

Connected Load	Annual Service Charge per hp.	Energy Charge in Addition to the Service Charge — Rate per kw-hr. for consumption per hp. per year: 1st 1000 kw-hr.	Next 1000 kw-hr.	All over 2000 kw-hr.
1-4.9 hp.	$6.25*	1.45¢	.7¢	.5¢
5-14.9 hp.	5.25	1.25	.7	.5
15-49.9 hp.	4.75	1.15	.7	.5
50-99.9 hp.	4.25	1.05	.7	.45
100-249.9 hp.	3.75	1.05	.7	.45

*In no case will the total annual service charge be less than $12.50 for single-phase service, nor less than $18.75 for three-phase service.

Example: Using our former example of a 25-hp. motor using 48,600 kw-hrs. in 1 year, and using the above rate, the total power bill is as follows:

Computation of total annual power bill:

Demand charge	- 25 x $4.75	= $118.75
Energy charge	- 1st 25,000 kw-hr. @ 1.15¢/kw-hr.	= 287.50
	Next 23,600 kw-hr. @ 0.7¢/kw-hr.	= 165.20
Total power bill (including demand charge)		$571.45

GENERAL INFORMATION

A. Static Water Level. The static water level is the vertical distance in feet from the center line of the discharge to the normal water level of water supply.

B. The Discharge Head consists of the vertical difference in elevation between the center line of the discharge from the pump head and the point of discharge from the pipe line together with any frictional losses in the pipe and any pressure head existing at the end of the pipe line.

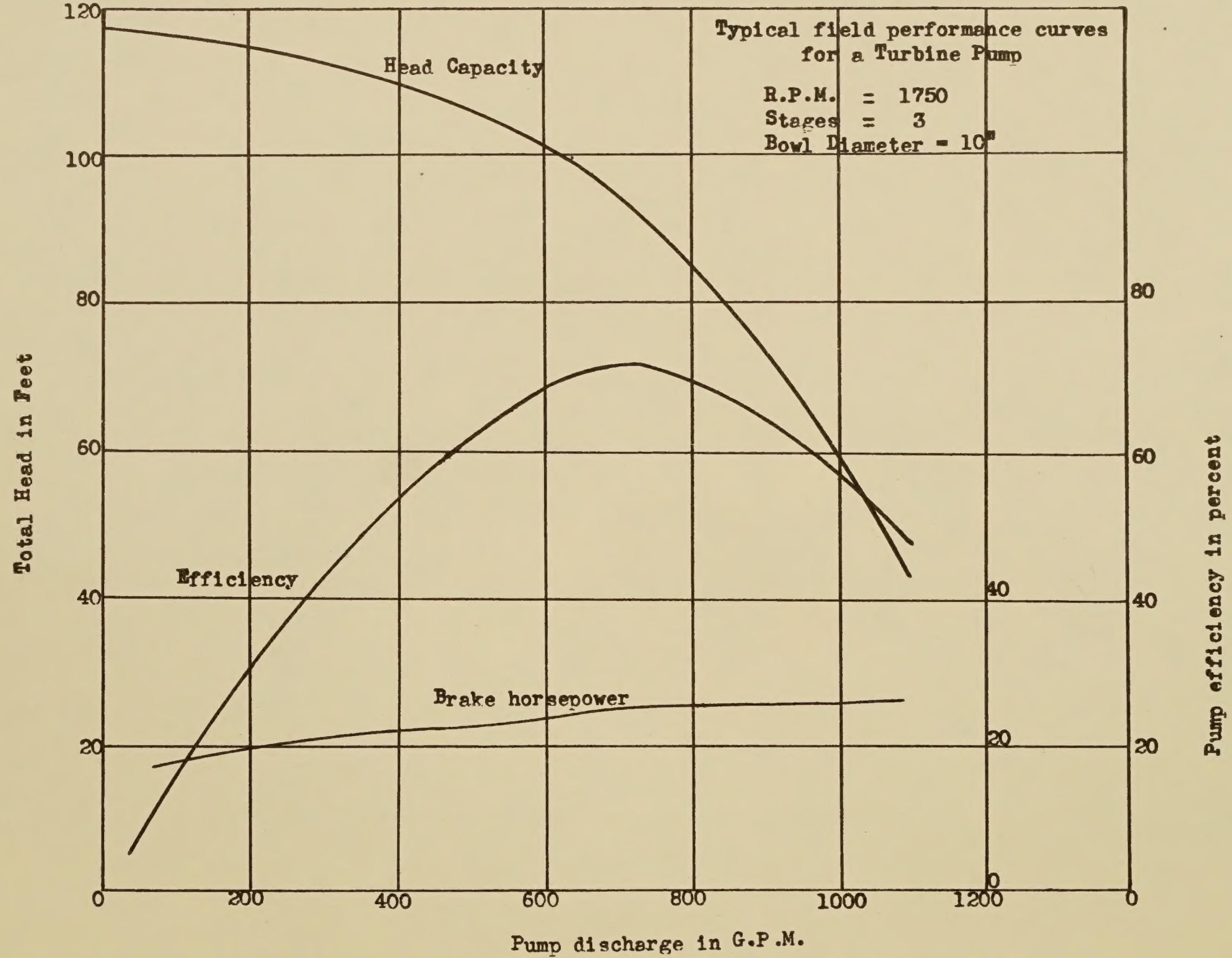
C. Total Head. The total head of an installed pump is the sum of the static water level, plus the drawdown, plus the discharge head measured in feet of water.

D. The purchaser of a pump should secure with the bid he obtains from his dealer a set of field performance curves for the pump that has been designed for his well. The performance curves will show the amount of water that the pump will deliver with various total heads (head-capacity curve); the efficiency of the pump for various rates of discharge (efficiency curve); and the brake horsepower that will be required to operate the pump at different rates of discharge (brake horsepower curve). The pump companies will furnish the field performance curves for any pump they design. These curves are the only means a purchaser has of knowing how the pump he is buying will perform.

7. Total head. The total head of an installed pump is the sum of the static water level, plus the drawdown, plus the discharge head expressed in feet of water.

8. The purchaser of a pump should secure with the bid he obtains from his dealer a set of field performance curves for the pump that has been designed for his well. The performance curves will show the amount of water that the pump will deliver with various total heads (head-capacity curve); the efficiency of the pump for various rates of discharge (efficiency curve); and the brake horsepower that will be required to operate the pump at different rates of discharge (brake horsepower curve). The pump companies will furnish the field performance curves for any specified design. These curves are the only means a purchaser has of knowing how the pump he is buying will perform.

GRAPH NO. 5



Typical field performance curves
for a Turbine Pump
R.P.M. = 1750
Stages = 3
Bowl Diameter = 10"
Head Capacity
Efficiency
Brake horsepower
Total Head in Feet
120
100
80
60
40
20
0
200
400
600
800
1000
1200
Pump discharge in G.P.M.
Pump efficiency in percent